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Dispatching rule-based scheduling algorithms in a single machine with sequence-dependent setup times and energy requirements

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Abstract

The research focuses on the problem of scheduling jobs in a single machine with sequence-dependent setup times and energy requirements in which jobs of multiple types arrive dynamically over time. A setup operation is required to change over the job types and it strongly depends on the sequence of the job types. During the setup operations, the machine tool is on idle state which means to consume an idle energy for non-machining on the machine tool. Moreover, frequent set-ups and long setup times negatively impact on the completion of the jobs as well as the idle energy consumption for the machine tool. Each job type has alternative process plans with different electricity machining energy requirements. The machining energy consumption which is incurred on the machine tool is defined from the perspective of the process plan. To cope with the dynamic nature of the scheduling problem, two energy efficient dispatching rule based algorithms are considered on the real time shop information with the objective of minimizing average energy consumption (with machining and non-machining) and mean tardiness of the finished jobs. The benefit coming from the adoption of suggested model has been addressed with reference to a real industrial use case study analyzed on the existing research.

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1. Introduction

In the last 50 years, the energy consumption by the industrial sector has more than double and the industry currently consumes about half of the world's energy [1]. The energy consumption is one of the most significant factors that lead manufacturing enterprises to become environmental unfriendly [2]. Recently, the higher energy cost and the growing concern over global warming have resulted in greater efforts toward reduction for the energy consumption. Most existing research on reducing the manufacturing energy consumption has focused so far on developing more energy efficient machines or machining processes at the machine and the factory level [3, 4].

Irrespective of the importance for energy consumed by the operations with the machining energy requirements, the energy requirements for the active removal of a material can be quite small [5]. Especially in the mass production environment, it

takes no more than 15 % of the total energy usage. The majority of energy is consumed by functions that are not directly related to the production of components [6]. This implies that efficiency improving efforts focusing solely on the machines or processes may miss a significant energy saving opportunity [2]. Nowadays, more efficient production approaches to reduce the machining energy consumption as well as non-machining energy consumption are strongly needed in the operational aspect.

From the operation point of view in a manufacturing system, a setup operation is required to changeover job types when jobs arrive continuously over time. The set-up includes obtaining tools, positioning work-in-process material, return tooling, cleaning up, setting the required jigs and fixtures, adjusting tools and inspecting material. Reducing the set-up times is an important task for better shop performance. Total set-up times are closely related to the number of set-ups and the time of each

set-up. A long set-up time directly impacts the processing, completion of each job and simultaneously the customer's satisfaction (i.e. tardiness and number of tardy jobs). Moreover, frequent set-ups and long setup times negatively impact on the non-machining energy consumption (i.e. idle energy consumption) for the machine tool. The more efficient operation approach to reduce the non-machining energy consumption needs to be considered strongly.

In this paper, we focus on a problem of scheduling jobs with the objective of minimizing average energy consumption (with machining and non-machining) and mean tardiness of the finished jobs in a single machine with sequence-dependent setup times and energy requirements. Under arrival for the jobs of multiple types dynamically over time, each job has alternative process plans with different energy requirements estimated on alternative operations with different machining process parameters (i.e. feed rate, cutting speed, processing time, etc). The set-up operations are not only often required between jobs when jobs arrive continuously over time but they are also strongly dependent on the immediately preceding job on the machine.

The research articles for a single machine scheduling problems with sequence-dependent setup times to minimize the total tardiness with or without weights of jobs are rich [7-10]. The amount of research on scheduling with environmentally-oriented objectives is currently increasing. Most of the current energy-conscious scheduling researches are a single machine and flow shop oriented and built up a multi-objective optimization model with the minimization for total energy consumption [11, 12]. Some of the energy-conscious scheduling research starts to focus on job shop environment [2, 13]. These researches are not enough to consider the dynamically arrival of the jobs with multiple type over time in a scheduling problem that considers the energy as well as the customer satisfactions.

For the electricity machining energy consumption, environmental analysis of machining on a basis of steady-state and transient regimes are taken into account [2, 14-16]. Some researches focus on the energy consumption for machining manufacturing considering alternative routes with different energy characteristics for the same job [15, 17]. Other researches focus on the scheduling problem with alternative process plans in a dynamic flexible job shop [18].

2. Problem description

There are some additional assumptions in this research to deal with a scheduling problem in a single machine with the sequence-dependent setup times and energy requirements. Parts with different types arrive dynamically over time. A machine can process only one part (at most one operation) at a time. Preemption is not allowed for processing each part, i.e., once an operation is started, it must be finished without interruption. The pallet types required for each part type can be different. There is no constraint that the number of pallets is limited. A part is mounted on a pallet. Each part type has alternative process plans with different process parameters (i.e. feed rate, cutting speed, process time, etc), alternative operation, different set-ups and different tools required. That is, each process plans

has different electricity machining energy requirements estimated on a basis of those parameters.

Once an operation related to a process plan of a part is started to process on the machine, a set of operations related to the process plan must be completed on without interruption. From the premises, a process plan can be considered as an operation for the part to be processed at the single machine. When the machine becomes available, an operation with highest priority value is selected among a set of eligible operations in the queue of the single machine. Then, the part with the selected operation is processed at the machine. In the paper, alternative process plans are modeled as alternative operations. Among available operations with different part types in a queue of the machine, the part related to the operation with highest priority is selected in order to be processed on the machine.

In a case of a changeover between parts with different types, a set-up operation is required on the machine. The total setup time required from the setup operation is the summation for some kinds of setup times, time for uninstalling tools for the currently setup type, time for installing tools for the new part type, time for changing a part program (i.e. NC code) with machining process parameters, time for cleaning up, time for inspecting and time for positioning for the new part types and it strongly depends on the sequence for those job types.

During the setup operation, the idle energy consumption for the non-machining is incurred on the machine. The idle state addresses one of a set of activities performed on a machine tool as long as the machine is turned on. The idle power represents a power drawn constantly as long as the machine is on which is a machine-specific value. There are some additional power consuming elements (i.e. hydraulic unit) that function on an intermittent basis. The idle energy consumption is estimated on the idle power drawn over the setup times.

The electricity machining energy consumption considered in this paper is estimated on existing research works for the mechanical machining energy consumption [19, 20]. The energy consumption is interpreted as a key performance index of the machine tool dynamics with respect to the required machining operations. The mechanical energy consumption required to perform the machining operation can be obtained by computing the integral of the mechanical power over the machining time as follows:

$$E_{tot} = E_{spindle} + E_{axes} \quad (1)$$

$$= \int_0^{T_{MWS}} \Omega_{spindle} \cdot T_{spindle}(t) \cdot dt + \int_0^{T_{MWS}} \vec{v}_{feed} \cdot \vec{F}_c(t) \cdot dt$$

where E_{tot} is total energy consumption for a machining working step (MWS- association between a machining feature and a machining operation). $E_{spindle}$ and E_{axes} is the energy consumption for the spindle and the energy consumption for the axes, respectively. In addition, $\Omega_{spindle}$ is the spindle velocity, $T_{spindle}$ is the spindle torque, \vec{v}_{feed} is the instantaneous feed velocity, $\vec{F}_c(t)$ is the cutting force and T_{MWS} is the MWS time duration.

The energy consumption is referred to the sole material removal [19]. It is noteworthy that Equation (1) does not

represent an estimation of the overall electrical power absorbed by the machine tool, but it is to be interpreted as mean to drive the choice of MWS alternatives [20]. The estimation of the electrical energy consumption can be more precisely computed by keeping separated axes and spindle mechanical power since the efficiency of the corresponding drives is usually different [14-16, 19].

Based on the analysis of the workpiece machining process, the process planning can decide an optimized set-up plan and pallet configuration. The outcome of the step is the generation of alternative process plans feasible [19, 21]. In this paper, a set of feasible alternatives process plans from a part is defined on the basis of MWS alternatives for the part. The machining energy requirement is estimated from Equation (1) in terms of alternative process plans with different operation, different machining process parameter.

3. Scheduling algorithm based on dispatching rules

Irrespective of consideration for the electricity machining energy consumption from the perspective for process plan, we assume that a process plan can be considered as an operation for a single machine. In the scheduling mechanism suggested in this paper, dispatching rules are used for job sequencing. When a machine becomes available for processing, an operation (which is a process plan for a part) that can be processed on the machine must be assigned on it. If two or more operations (which mean a set of process plans for the parts) are ready to be processed on the same machine, one of the operations in queuing parts of the machine has to be selected according to the dispatching rule, which can calculate priorities of the operations. That is, a process plan for a job with highest priority is selected among a set of eligible process plans that can be processed on the machine according to priorities.

Processing times of parts at the machine are dependent on part types, that is, the processing times for parts of the same type are identical. A set-up operation is required to changeover part types at the machine. The set-up times directly impact the processing, completion of each part and simultaneously the customer's satisfaction (i.e. tardiness). Moreover, frequent set-ups and long set-up times negatively impact on the non-machining energy consumption (i.e. idle energy consumption) for the machine tool. To find more effective solution for a real time scheduling problem in a single machine, we propose newly dispatching rules based scheduling algorithms with the consideration of the processing time of parts, due date of parts, setup time as well as machining energy consumption of parts.

Before describing the dispatching rules, we give the notation needed to define the priorities of the operations in the rules.

Nomenclature

i	operation
j	part
t	current time
j_i	operation i related to part j
w_{j_i}	weight for imminent operation i of part j
p_{j_i}	processing time of imminent operation i of part j due-date of imminent operation of part s_{cj} setup time for

\bar{s}	imminent operation of part j
\bar{s}	average setup time for imminent operations of queuing parts from the current state
$E_{j_i}^{ME}$	machining energy consumption (kJ) of imminent operation of part j

The newly dispatching rules developed in this paper are represented in Table 1.

Table 1. Newly developed dispatching rules

Rule	Equation
ATCS_ME1	(Apparent Tardiness Cost with Setups and Machining Energy consumption 1) $\frac{w_{j_i}}{E_{j_i}^{MC}} \cdot \exp\left(-\frac{\max(d_{j_i} - p_{j_i} - t, 0)}{k_1 \bar{p}}\right) \exp\left(-\frac{s_{cj}}{k_2 \bar{s}}\right)$
ATCS_ME2	(Apparent Tardiness Cost with Setups and Machining Energy consumption 2) $\frac{w_{j_i}}{p_{j_i}} \cdot \frac{1}{E_{j_i}^{MC}} \exp\left(-\frac{\max(d_{j_i} - p_{j_i} - t, 0)}{k_1 \bar{p}}\right) \exp\left(-\frac{s_{cj}}{k_2 \bar{s}}\right)$

Formulation of two dispatching rules (ATCS_ME1 and ATCS_ME2) is newly developed on a basis of the ATCS (Apparent Tardiness Cost with Setups) rule which is well known dispatching rule. The ATCS rule consists of three terms: shortest process time (SPT), minimum slack (MS) and shortest setup time (SST). The first term denotes the SPT rule designed to select the job with the shortest process time. The second term (MS) ensures that the job with minimum slack time is chosen. The final term (SST) ensures that sequence dependent setup time is considered when jobs are selected.

Based on those three terms (SPT, MS and SST), the new developed dispatching rules add a term for the machining energy consumed to process one operation at the machine. The new two rules can incorporate minimum energy consumption assurance to the overall operation selection rules. First of all, the ATCS_ME1 rule consists of three terms as follows: MS, SST as well as minimum machining energy consumption (MMEC). The operation with high priorities indicates minimum slack time, shortest setup time as well as minimum machining energy consumption. Secondly, the ATCS_ME2 rule consists of four terms as follows: SPT, MS, SST as well as MMEC. The priority value of the rule increases with shorter process time, minimum slack time, shortest setup time and minimum machining energy consumption.

For the suggested two dispatching rules, the values of $1/p_{j_i}$ from the SPT rule are between 0 and 1. The amount of slack time by employing the MS rule forces the term to converge to 1 and large slack leads to 0. The term from the SST rule is also between 0 and 1. A large sequence-dependent setup time results in a small value and a short setup time will incur a large value. Parameters k_1 and k_2 are scaling parameters. Based on the

results from Lee et al. (1997), the values are set as 1.6 and 3.0. Finally, the term from machining energy consumption to produce one operation is between 0 and 1. A large energy consumption results in a small value and small energy consumption also results in a large value.

4. Simulation test on a case study

The proposed approach is tested on existing research works provided on an industrial company operating in the motorbike sector as a subcontractor. The considered parts undergo frequent technical modification and a variable demand. The characteristics of the part types as well as the machining energy consumption are reported from previous researches [20-23]. In the existing research, the part types are analyzed on a same 4-axis machine tool (MCM Clock 600CIM horizontal machine).

First of all, Copani *et al.* (2012) and Pellegrinelli *et al.* (2012) analyzed a part (code 492), which is called as a part 'WPD' in this paper, produced for the recreational market (snowmobiles, outboards engines, all-terrain vehicles). The part is characterized by 63 MWSs with 2 face milling operations. Then, Copani *et al.* (2015) and Pellegrinelli *et al.* (2015) analyzed a family of parts composed of three part types: first part 'WPA' is a medium-size engine carter for motorcycle industry characterized by 23 MWSs (21 drilling operations and 2 milling operation), the second part 'WPB' is a 4 stroke cylinder characterized by 41 MWSs (37 drilling operations and 4 milling operations) and the third part 'WPC' is a medium-size engine carter characterized by 24 MWSs (22 drilling operations and 2 milling operations).

The machining energy consumption for a set of MWSs of the 4 parts is analyzed on the 4-axis machine tool. In terms of the key performance indicators such as energy consumption, spindle load, cutter load, surface roughness, required spindle torque and required spindle power, MWS alternatives are analyzed on the same machine type in more detail. On the basis of the MWS alternatives for the parts from existing research works, a set of alternatives process plans for the parts are defined and the machining energy consumption is estimated on the 4-axis machine tool with respect to alternative process plans.

For an example for the machining energy requirements of alternative process plans of a part, part 'WPD' has three MWS alternatives regarding MWS-#25 and MWS-#26 of the part 'WPD', respectively. Here, the MWS-#25 and MWS-#26 means face milling operations. Each MWS alternative has different cutting parameters (i.e. feed rate, spindle speed, cutter depth, processing time, Material removal rate) and also different key performance indicators (i.e. surface roughness). The part 'WPD' has three alternative process plans (i.e. WPD-PP-1, WPD-PP-2, WPD-PP-3) based on three MWS alternatives regarding MWS-#25 and MWS-#26. Here, the cutting process parameters for other MWSs excluding MWS-#25 and MWS-#26 are the same. The energy consumption for three alternative process plans can be calculated from the equation 1 defined in section 2. The difference of the energy consumption between alternative process plans for a part is due to different machining process parameters such as feed rate, spindle speed, cutter depth and processing time.

For many machining processes, the processing time required to perform a part may be reduced by increasing the machine speed, with the consequence generally being increased peak power demand [13]. In some cases, the lower spindle speed employed for part program machining is more than energy demanding than the machining in the higher speed range [14]. The case with the lower spindle speed has longer processing times and it causes more idle energy consumption. Table 2 represents the machining energy consumption and processing time for alternative process plans of the considered four parts from the existing research. In the case of the part 'WPC', two alternative process plans (i.e. WPC-PP-2, WPC-PP-3) with reduced process time have more increased energy consumption than the process plan 'WPC-PP-1'. It's because the difference of the energy consumption is depending on different machining parameters (i.e. feed rate, spindle speed).

Table 2. Energy consumption and process time for the considered parts

Part	Process plan	Processing time (sec)	Machining Energy Consumption (kJ)
WPA	WPA-PP-1	261.0	19.2
	WPA-PP-2	247.0	20.5
	WPA-PP-3	247.0	20.9
	WPA-PP-4	245.5	78.0
	WPA-PP-5	257.0	71.9
WPB	WPB-PP-1	186.5	16.7
	WPB-PP-2	186.5	28.9
WPC	WPC-PP-1	193.6	11.3
	WPC-PP-2	185.0	32.1
	WPC-PP-3	189.1	25.3
WPD	WPD-PP-1	282.4	92.3
	WPD-PP-2	280.2	84.7
	WPD-PP-3	279.0	84.5

Although the number of MWSs to produce one unit of the parts are more two MWSs for each alternative process plans, we model a process plan to one operation to be produced on the single machine because it must be finished without interruption when one operation related to the process plan is started on the machine. That is, to select one operation among a set of eligible operations means to select a process plan among a set of eligible process plans.

At each time when the machine becomes available, the operation with the highest priority is selected among a set of eligible operations from all eligible parts to be processed at the machine in the queue. The part related to the operation is processed on the machine. In a case of a changeover between parts with different types, a sequence-dependent setup time should be inserted to process the new part. During the setup times, the idle energy consumption for the non-machining is estimated on a basis of average idle power measured from all power driven resources of the 4-axes machine tool. Due to the intermittent functioning of additional components such as pump of the hydraulic, refrigeration unit of the spindle and axes lubrication pump, the idle power for the machine can be measured at 3.13kW [15].

A series of computational experiments was performed for an evaluation of the performance of the rules suggested in this study. For the experiments, 720 problems were generated randomly, 20 problems for each of 36 scenario cases generated according to the variations in three factors: four levels for inter-

arrival range parameter (α : 0.4, 0.5, 0.6, 0.7), three levels for due-date range parameter (β : 1.5, 2.0, 2.5) and three levels for setup range parameter (γ : 0.2, 0.5, 0.8). For each problem instance, the test runtime is set to 20,000 and the number of considered part type is fixed to 4 (i.e., WPA, WPB, WPC, WPD) as seen in Figure 1.

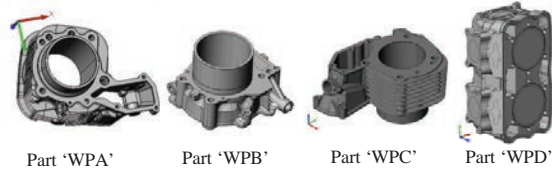


Fig. 1. Considered four part types.

Other data were generated in such a way that the resulting problems reflect real situations relatively well. A process time of a part is estimated from average time on alternative process plans of the part. The setup time for a part can be estimated in terms of each process plan for the part. The setup time is generated by multiplying the setup range parameter and the processing time for one (i.e. selected process plan) of alternative process plans for the part. The inter-arrival times between parts are exponentially generated with the mean $\mu = \alpha \cdot (s+p)$. Here, s and p means average setup time and average process time for the considered parts, respectively. When a part j arrives, each part and its due date is generated randomly by the equal ratio for considered parts and by a uniform distribution.

The two dispatching rules (ATCS_ME1 and ATCS_ME2) suggested in this study were compared with three existing dispatching rules (Slack/RW, MST and ATCS) on the 720 test problems generated as described above. The suggested two rules are strongly related to minimum machining energy consumption. In ATCS, ATCS_ME1 and ATCS_ME2 rules, the parameters (k_1 and k_2) are set by using the rules suggested by [24].

Overall results of the test are given in Table 3, which shows average energy consumption and mean tardiness of the finished parts within the limited simulation runtime for five dispatching rules. Slack/RW (Slack per remaining work), which is a well-known dispatching rule, shows worst results in terms of both performances, average energy consumption and the mean tardiness, because it causes a lot of set-up operations. MST (Minimum Setup Time) rule also shows bad results in terms of both performances. Meanwhile, three dispatching rules (ATCS rule, ATCS_ME1 rule and ATCS_ME2) considering simultaneously MS and SST have better performances than the other rules (Slack/RW and MST) in terms of two performance measures.

From the perspective of overall energy consumption with machining and non-machining, both ATCS_ME1 rule and the ATCS_ME2 rule performs better than the others as can be seen from Table 3. The suggested rules show less average energy consumptions, reduced by 76.5% and 73.4%, respectively, than that of Slack/RW because it causes less idle energy consumption caused by reduced setup time. Moreover, the suggested rules show less average energy consumption, reduced by 40.7% and 33.1%, respectively, than that of ATCS

rule. ATCS_ME1 shows the best performance in terms of average energy consumption. From the perspective of the mean tardiness, ATCS, ATCS_ME1 and ATCS_ME2 rules perform better than the other rules because the rules consider MS and SST, simultaneously. Three rules show less mean tardiness, reduced by more 50%, than that of Slack/RW. ATCS_ME2 shows the best performance in terms of the mean tardiness. Meanwhile, ATCS rule performs better than ATCS_ME2 in some scenario cases.

Table 3. Overall performance of the dispatching rules

param eter		Slack/RW	ATCS	MST	ATCS_ME 1	ATCS_ME 2
		Energy (kJ) Tardiness (sec)	Energy (kJ) Tardiness (sec)	Energy (kJ) Tardiness (sec)	Energy (kJ) Tardiness (sec)	Energy (kJ) Tardiness (sec)
α	0.4	144.9	46.0	109.1	25.8	27.3
		5614.6	2306.1	3287.9	2451.7	2336.4
	0.5	145.1	53.2	97.8	29.4	33.0
		4675.0	1950.5	3196.4	2163.2	1934.9
	0.6	144.3	61.0	93.2	36.5	41.7
		3753.4	1621.5	2706.2	1775.8	1586.4
	0.7	144.7	69.5	98.6	44.5	51.6
		2871.9	1386.9	2106.5	1432.7	1313.2
β	1.5	144.0	57.9	101.5	34.3	38.8
		4396.4	1934.7	2961.2	2034.8	1902.6
	2.0	144.9	56.9	99.3	33.9	38.4
		4228.6	1793.8	2816.5	1960.3	1789.7
	2.5	145.4	57.5	98.2	34.0	38.0
		4061.2	1720.3	2695.0	1872.5	1686.0
γ	0.2	103.4	43.7	96.0	22.3	23.4
		4913.2	2108.7	3237.8	2207.7	2169.7
	0.5	144.6	56.6	97.2	32.7	37.2
		4201.3	1868.2	2846.0	2005.2	1772.2
	0.8	186.3	72.0	105.8	47.2	54.6
		3571.7	1471.9	2389.0	1654.7	1436.3
Avera ge		144.8	57.4	99.7	34.1	38.4
		4228.7	1816.3	2824.3	1955.9	1792.7
		144.8	57.4	99.7	34.1	38.4
		4228.7	1816.3	2824.3	1955.9	1792.7

5. Conclusion

Irrespective of the importance for the machining energy consumption in a manufacturing environment, the efforts on reducing non-machining energy consumption are strongly needed in the operational aspect. The paper focuses on a single machine scheduling problem with the sequence-dependent setup times and energy requirements with the objective of minimizing average energy consumption (with machining and non-machining) as well as mean tardiness for the jobs of multiple types with dynamic arrival over time. From the results of tests on data analyzed from existing research, the two suggested rules (ATCS_ME1 and ATCS_ME2) show better performance than the other existing rules in terms of average energy consumption and the mean tardiness.

References

- [1] Mouson G, Yildirim MB, Twomey J. Operational methods for minimization of energy consumption of manufacturing equipment. *International Journal of Production Research* 2007;45:4247-4271.
- [2] Liu Y, Dong H, Lohse N, Petrovic S, Gindy N. An investigation into minimizing total energy consumption and total weighted tardiness in job shops. *Journal of Cleaner Production* 2014;65: 87-96.

- [3] Herrmann C, Thiede S, Kara S, Hesselbach J. Energy oriented simulation of manufacturing systems – concept and application, *CIRP Annals – Manufacturing Technology* 2011; 60; 45-48.
- [4] Bonvoisin J, Thiede S, Brissaud D, Herrmann C. An implemented framework to estimate manufacturing-related energy consumption in product design. *International Journal of Computer Integrated Manufacturing* 2013; 26; 866-880.
- [5] Dahmus JB, Gutowski TG. An environmental analysis of machining. In: *Proceedings of IMECE 2004*, November 13e19, Anaheim, California, USA. 2004;
- [6] Gutowski T, Murphy C, Allen D, Bauer D, Bras B, Piwonka T, Sheng P, Sutherland J, Thurston D, Wolff E. Environmentally benign manufacturing: observations from Japan, Europe and the United States. *Journal of Cleaner Production* 2005;13;1-17.
- [7] Lee YH, Bhaskaran K, Pinedo M. A heuristic to minimize the total weighted tardiness with sequence dependent setups. *IIE Transaction* 1997; 29; 45-52.
- [8] Lin SW, Ying KC. Solving single-machine total weighted tardiness problems with sequence-dependent setup times. *International Journal of Advanced Manufacturing Technology* 2007;34;1183-1190.
- [9] Ying K-C, Lin S-W, Huang C-Y. Sequencing single-machine tardiness problems with sequence-dependent setup times using an iterated greedy heuristic, *Expert Systems with Application* 2009;36;7087-7092.
- [10] Subramanian A, Battarra M, Potts CN. An iterated local search heuristics for the single machine total weighted tardiness scheduling problem with sequence-dependent setup times, *International Journal of Production Research* 2014;52;2729-2742.
- [11] Mouson G, Yildirim MB. A framework to minimise total energy consumption and total tardiness on a single machine. *International Journal of Sustainable Engineering* 2008;1;105-116
- [12] Yildirim MB, Mouzon G. Single-machine sustainable production planning to minimize total energy consumption and total completion time using a multiple objective genetic algorithm, *IEEE Transaction on Engineering Management* 2012;59, 585-597.
- [13] Fang K, Uhan N, Zhao F, Sutherland JW. A new shop scheduling approach in support of sustainable manufacturing. 18th *CIRP LCE Conference*, Braunschweig 2011;305-310.
- [14] Avram IO, Xirouchakis P. Evaluating the use phase energy requirements of a machine tool system. *Journal of Cleaner Production* 2011;19; 699-711.
- [15] Choi Y-C, Xirouchakis P. A production planning in highly automated manufacturing system considering multiple process plans with different energy requirements. *International Journal of Advanced Manufacturing Technology* 2014;70;853-867.
- [16] Choi Y-C, Xirouchakis P. A holistic production planning approach in a reconfigurable manufacturing system with energy consumption and environmental effects. *International Journal of Computer Integrated Manufacturing* 2015;28;379-394.
- [17] He Y, Liu B, Zhang X, Gao H, Liu X. A modelling method of task-oriented energy consumption for machining manufacturing system. *Journal of Cleaner Production* 2012;23;167-174.
- [18] Rajabinasab A, Mansour S. Dynamic flexible job shop scheduling with alternative process plans: an agent-based approach. *International Journal of Advanced Manufacturing Technology* 2011;54;1091-1107.
- [19] Leonesio M, Molinari Tosatti L, Pellegrinelli S, Valente A. An integrated approach to support the joint design of machine tools and process planning. *CIRP Journal of Manufacturing Science and Technology* 2013;3;181-186
- [20] Copani G, Leonesio M, Molinari Tosatti L, Pellegrinelli S, Urgo M, Valente A. An integrated framework for combined designing dematerialized machine tools and production systems enabling flexibility-oriented business models. *International Journal of Computer Integrated Manufacturing* 2015;28;353-363.
- [21] Pellegrinelli S, Valente A, Molinari Tosatti L. Energy-efficient distributed part programme for highly automated production systems. *International Journal of Computer Integrated Manufacturing* 2015;28;395-407.
- [22] Copani G, Leonesio M, Molinari Tosatti L, Pellegrinelli S, Urgo M, Valente A, Zulaika J. Holistic approach for jointly designing dematerialized machine tools and production systems enabling flexibility-oriented business models. *Leveraging Technology for a Sustainable World* 2012;209-214.
- [23] Pellegrinelli S, Valente A, Molinari Tosatti L. An integrated setup planning and pallet configuration approach for highly automated production system with energy modelling of manufacturing operations. 45th *CIRP Conference on Manufacturing System* 2012;49-54.
- [24] Lee YH, Pinedo M. Scheduling Jobs on Parallel Machines with Sequence-dependent Setup Times. *European Journal of Operational Research* 1997;100;464-474.